

Research papers

Dam site suitability assessment at the Greater Zab River in northern Iraq using remote sensing data and GIS



Abbas Mohammed Noori^a, Biswajeet Pradhan^{b,c,*}, Qayssar Mahmood Ajaj^a

^a Department of Surveying Techniques Engineering, Technical College of Kirkuk, Northern Technical University, Kirkuk 36001, Iraq

^b The Centre for Advanced Modelling and Geospatial Information Systems (CAMGIS), Faculty of Engineering and Information Technology, University of Technology Sydney, 2007 New South Wales, Australia

^c Department of Energy and Mineral Resources Engineering, Choongmu-gwan, Sejong University, 209 Neungdong-ro Gwangjin-gu, Seoul 05006, Republic of Korea

ARTICLE INFO

This manuscript was handled by G. Syme, Editor-in-Chief

Keywords:

Dam site suitability

Remote sensing

GIS

Multi-criteria decision analysis

Fuzzy

AHP

ABSTRACT

In the last few decades, the northern region of Iraq has been severely impacted by climate change, which has created long-term drought, water shortage, and casual flood events. Dam construction in suitable sites is a primary water management strategy to solve flood and drought. Dam site selection depends on a set of qualitative and quantitative criteria, such as geology, soil type, and altitude. In this study, appropriate areas of dam site selection for water management were identified using remote sensing, geographic information system (GIS), and multi-criteria decision making techniques. In addition, the proposed method of site suitability was evaluated by comparing it with the traditional analytic hierarchy process (AHP). A new validation method to evaluate the accuracy of AHP and fuzzy logic according to the preselected location of a dam was previously suggested in the study area (Bekhme dam) by the local government. Remote sensing data (Landsat imageries and ASTER DEM) and field/reference maps were used to derive 12 conditioning factors needed to produce a suitability map for construction. The criteria considered were geological formation, soil type, fault line, tectonic line, altitude, slope, rainfall data (2000–2011), water discharge, land use/cover, road network, and material used for dam construction. Two mathematical models, namely, AHP and fuzzy logic, were applied in this study. The best model was selected by using location and cluster-based accuracy assessment depending on the proposed dam site (i.e., Bekhme dam). Results showed that fuzzy logic is more accurate than AHP. In terms of the surface area of suitable lands identified, the AHP model determined 13,446,900 m² as a highly suitable area, whereas the fuzzy model identified 3,409,200 m² from the total area of 69,347,700 m². Finally, this study identified four sites for intermediate and large dams in the study area. The total water capacities of proposed Dam 1, Dam 2, Dam 3, and Dam 4 are about 81.5, 239.3, 374.6, and 646.5 million m³, respectively, when the dam height is 60 m. The proposed methods can be easily replicated to other areas for similar applications. The finding reveals that AHP model is distributed and scattered in the whole study area, whereas the fuzzy model is more suitable for clustered areas.

1. Introduction

Water demand is increasing because of climate change and rapid population growth (Schewe et al., 2014). Iraq is an agricultural country wherein the demand for water has been growing for more agricultural production to guarantee food security. The main source of irrigation water is rivers.

Proper location of dams in rivers could control floods (Skalak et al., 2013) and provide hydropower energy for surrounding residential areas. The need to constructing dam has been increasing to meet the required of drinking water supply, irrigation, water resource

productivity, drought control system, and the influence of this construction can be social, environmental and economic (Altinbilek, 2002). Dam site selection is one of the main problems in the water resources management. Upper Zab River is one of the important rivers in the north of Iraq. This river provides water for irrigation and water supply. However, the major problem with this river is that there are no dams built on it. The problem of having no dams on this river could effect on urban flooding, water shortage and reducing the important water of irrigation.

GIS and Multi-Criteria Decision Analysis (MCDA) are efficient tools for spatial analysis and decision making (Malczewski, 2004; Islam et al.,

* Corresponding author at: The Centre for Advanced Modelling and Geospatial Information Systems (CAMGIS), Faculty of Engineering and Information Technology, University of Technology Sydney, 2007 New South Wales, Australia.

E-mail address: Biswajeet.Pradhan@uts.edu.au (B. Pradhan).

<https://doi.org/10.1016/j.jhydrol.2019.05.001>

Received 27 April 2018; Received in revised form 29 April 2019; Accepted 1 May 2019

Available online 04 May 2019

0022-1694/ © 2019 Elsevier B.V. All rights reserved.

2018; El-Shirbeny et al., 2018). Decision analysis involves a set of systematic procedures to assess complex decision problem (Malczewski, 1999) which is usually evaluated by various individuals, including managers, decision makers, stakeholders, and interest group members, who often display unique preferences for criteria used in the evaluation.

Accordingly, multi-criteria decision making (MCDM) and GIS are integrated to increase the analysis capabilities for site suitability (Abdulkareem et al., 2018a,b; Althuwaynee et al., 2012, 2014). GIS is used to in detail analyze the spatial decision context, whereas MCDM is applied to compare alternatives (Abdullahi et al., 2014). A few critical aspects of MCDM are having a restricted set of substitutes and an overtly distinct set of alternatives, thereby necessitating information on the decision maker's choices and having a focus on outcomes (Chakhar et al., 2003). When solving an MCDM, an individual must know the significance or weight of the unsubstantial attributes as well as the assessments of the alternatives with respect to the attributes. The most recognized MCDM methods are simple additive weight, ideal point method, analytical hierarchy process (AHP), and fuzzy logic. A lot of research has been done on dam site selection methods and affected factors (Safavian and Amani, 2015; Forzieri et al., 2008; Yasser et al., 2013; Minatour et al., 2015; Abushandi and Alatawi, 2015; Tsiko and Haile, 2011; Thanoon and Ahmed, 2013; Ahmad et al., 2013; Qureshi, 2015). Also, there are many papers have been published on dam site selection and hydropower energy site selection (Fitzgerald et al., 2012; Larentis et al., 2010; Rajeev and Mahesha, 2018; Jamali et al., 2014; Rojanamon et al., 2009).

A previous study found that the commonly used AHP method is human subjective and that the results could be easily biased (Chan and Kumar, 2007). To overcome this problem, fuzzy logic was suggested in this research for suitable dam site selection. In specific, fuzzy logic has the ability to deal with vague control rules expressed by human language (Molina et al., 2017; Chung et al., 2017). Fuzzy logic is an efficient method when it comes to dealing with unclear features (Li et al., 2017). This technique requires a degree of importance for GIS layers that can be expressed by values between 0 and 1, i.e., 1 for the most important suitable land and 0 for the least important one (Van et al., 1996).

AHP introduces the concept of hierarchical thinking, but some uncertain variables (i.e. expert weightage) may confuse decision making (Emamgholi et al., 2015). The traditional AHP requires crisp judgments. However, a decision maker may feel more confident to provide fuzzy judgments than crisp comparisons because of the complexity and uncertainty involved in real-world decision problems. Fuzzy decision making is a powerful paradigm of dealing with human expert knowledge. This method has been used to solve or support spatial reasoning problems in different contexts, such as locating convenience stores and selecting other sites (Ahamed et al., 2000; Burrough et al., 1992; Lewis et al., 2014; Qiu et al., 2014; Sicat et al., 2005; Stoms et al., 2002). However, AHP is limited by the difficulty in obtaining ideas and is predisposed to human subjectivity. Previous studies suggested alternative techniques for suitability application, such as fuzzy logic (Keshavarzi et al., 2010). Fuzzy logic site selection is commonly used when uncertain elements are present and when a site cannot be specified (Charabi et al., 2011; Markowski et al., 1977; Liu et al., 2016).

The present study aims to identify appropriate areas for the construction of dams by using remote sensing, GIS, and MCDM technique. Due to the requirement of the reservoir's capacity in the region, dam sites suitability has been proposed along the Greater Zab River. AHP and fuzzy logic were applied to select suitable sites for constructing dams on the selected river in the study area. The proposed dams are also characterized.

2. Study area

The Greater Zab is an approximately 437 km long river that flows through Turkey and Iraq (Fig. 1. (a)). The river rises in Turkey near

Lake Van and connects with the Tigris in Iraq south of Mosul City (Awchi, 2014). It supplies 28.7% of the water in the Tigris (Al-Ansari et al., 2014). Approximately 300 km of the river's course is located within Iraq. Rainfall and snowmelt are the primary sources of water in the river and its tributaries, and the resulting discharge highly fluctuates throughout the year (Al-Ansari et al., 2014). Fig. 1b shows the annual rainfall map of the study area. The Great Zab, which originates in Turkey, generates 13.18 km³ at its confluence with the Tigris; 62 % of the total area of this river basin of 25 810 km² is in Iraq (FAO).

Of the Tigris tributaries, the Greater Zab River has the largest water yield. The headwaters of this river originate from the Ararat Mountains in Turkey at an altitude of 4,636 m asl. The headwater topography features steep slopes, and several tributaries and wadis, including Khazir, Rubari Shin, Rukuchuk, and Rubat Mawaran Rivers, flow into the Greater Zab River.

3. Methodology

The overall methodology of this research is shown in Fig. 2. To find suitable sites for dam construction, various types of data were collected from different sources. Satellite Imagery (Landsat 8 OLI) was downloaded from the USGS website which has 30 m spatial resolution. Images taken on August 2014 were pre-processed, processed, and then post-processed to produce the land use and land cover map of the study area. In this study, ENVI software was used to produce land use and land cover map while ArcGIS software was used to produce other maps. Digital Elevation Model (DEM, 30 m × 30 m) was extracted from ASTER GDM in Raster formats, and the data were mosaicked. The DEM data was acquired on 17 October 2011. DEM was used to extract the drainage network, elevation, and slope of the study area. The topography of the study area is complex in terms of relief variation. Geological, soil, and tectonic maps of northern Iraq were obtained from the Ministry of Industry and Minerals (Iraq Geology Survey). The geological map was updated in 2014, and its scale is 1:250,000; the scales of the soil and tectonic maps are both 1:1,000,000. The main roads of the region were extracted from the Base Map of Duhok governorate prepared by Joint Humanitarian Information Center, and the scale of this map is 1:100,000.

Climate data were obtained from the Meteorological Department of Kurdistan Region Government in Iraq. The annual rainfall data from 2000 to 2011 were also procured. The study area covers 25 climatological stations. Annual discharge data were provided by the Department of Dams and Reservoirs of Kurdistan Region Government in Iraq. Criteria with direct influence on the land suitability of dam site selection were selected. These criteria include geological formation, soil, tectonic, fault, elevation, slope, rainfall, river discharge, materials for earth dam construction, and urban and rural areas and roads. Two MCDM models, namely, AHP and fuzzy logic, were used to determine the land suitability for dam site selection. The model with the highest accuracy was compared on the basis of the proposed dam (Bekhme dam) in the study area. Subsequently, four suitable sites were identified and proposed for dam construction. In addition, the length and water storage of each dam were calculated. Finally, the dam site was ranked according to the length and water storage of each dam.

3.1. Data used

Based on the literature review, this study selected 12 criteria (Fig. 3) for the determination of suitable areas for dam construction: rainfall, slope, river discharge, soil texture, geology, distance from urban and rural areas, distance from fault and tectonic lines, distance from the main road, and distance from the available material for dam construction.

Hydrological parameters such as stream network flow accumulation, altitude, and slope were derived from the DEM using ArcGIS 10.3 software. The altitude map was derived from the DEM of the study area.

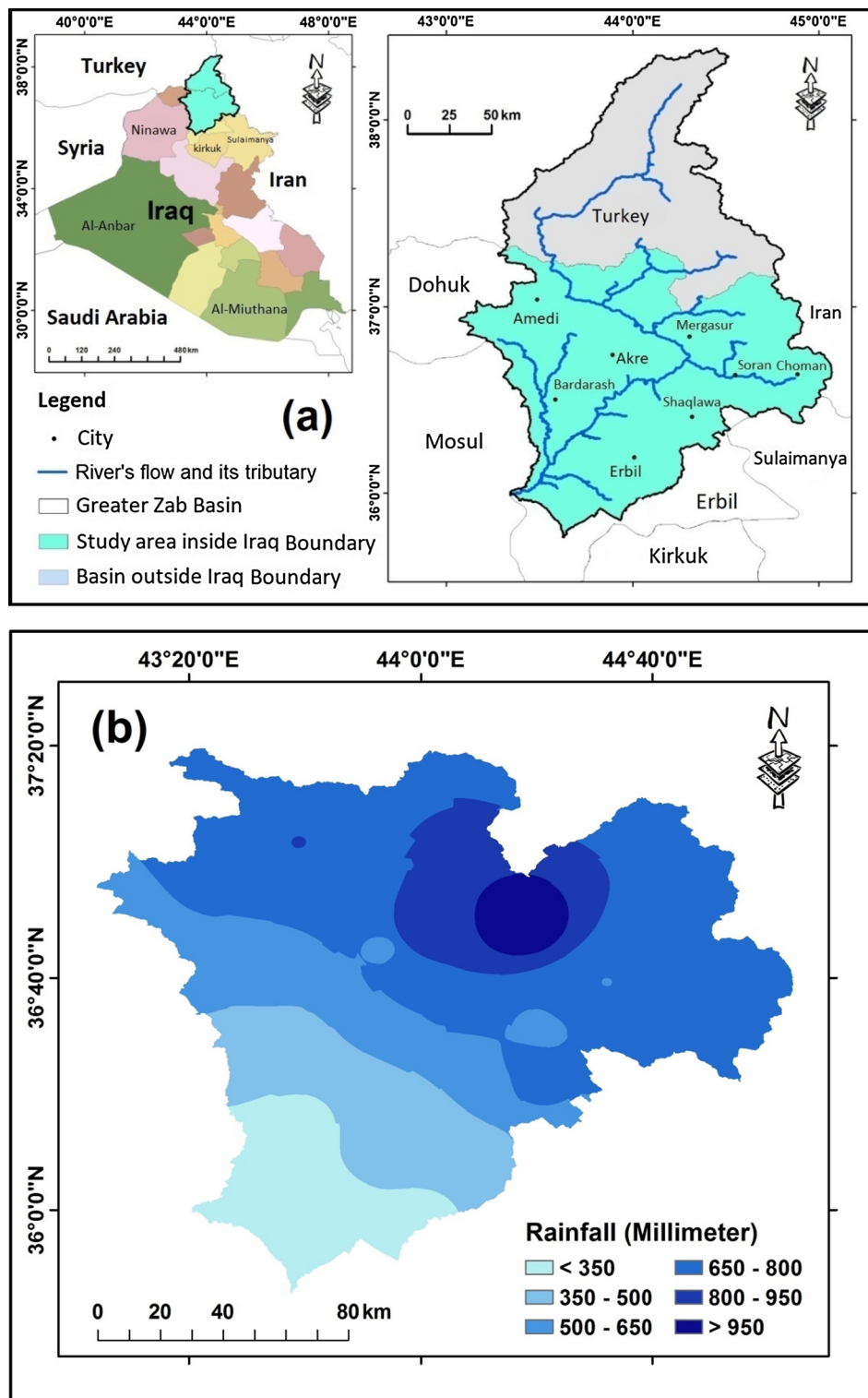


Fig. 1. (a) Study area and the Greater Zab River basin; (b) Rainfall map of the study area.

The elevation ranged from 180 m to 3600 m above sea level. The slope map was extracted from the DEM (Lewis et al., 2014) and is classified into five percentage classes according to the Food and Agriculture Organization of the United Nation (FAO) (Lewis et al., 2014). The classes were generated according to the defined interval in five zones, namely, < 2°, 2°–8°, 8°–15°, 15°–30°, and > 30°. Slope steepness is an important consideration when assigning and implementing dam sites (Lewis et al., 2014). The study area is characterized by gentle slopes on the southwest part while steep slopes and deep valleys on the north and

northeast parts.

The study area displays five types of land cover: bare soil, urban, rural, water, and vegetation (Fig. 4). Land cover, which is an important criterion in dam site selection, was derived from the Landsat image. In this study, Maximum Likelihood (ML) classifier was used to classify the Landsat data with a classification accuracy of 91%. Field surveyed data were used as training and testing to evaluate the classification accuracy of the land cover map which is extracted from the Landsat images (Noori et al., 2018). In this study, 70 ground control points (GCPs) were

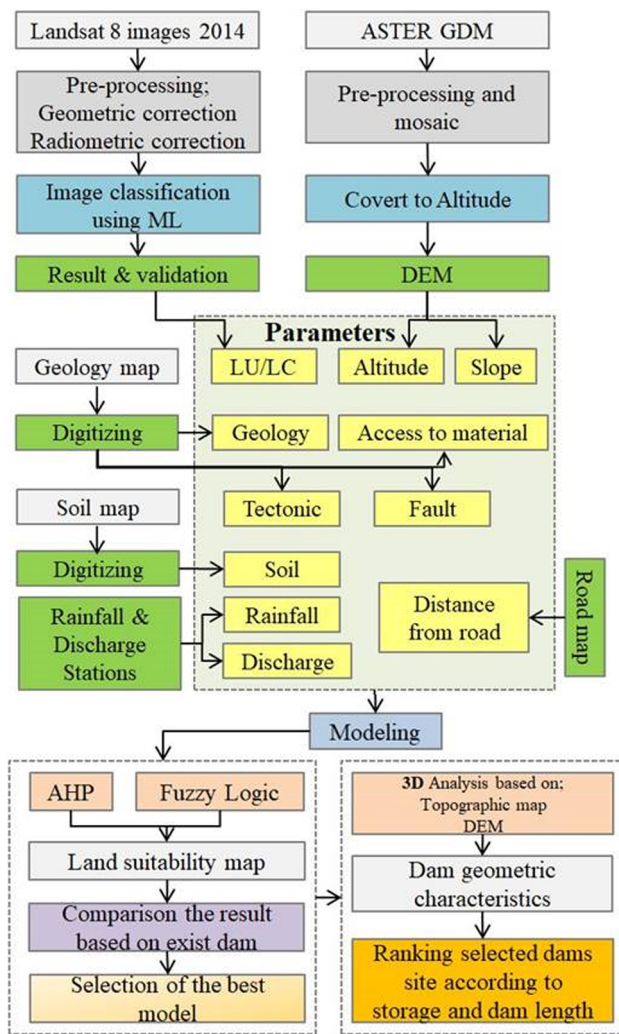


Fig. 2. Overall flowchart of dam site selection used in this study.

used as training data and 30 GCPs as testing data. (ML) classifier has shown high accuracies especially in mapping land use land cover (Ajaj et al., 2017). Previous research showed that the distance from urban areas influences dam site selection. To prevent possible hazards, dams must be located as far as possible from residential areas. Distances less than 2500 m are considered inappropriate, and regions with longer distances achieve higher rates (Ghazal et al., 2015). The distance from rural areas must be considered to avoid hard reaching regions in the construction phase. Proximity to a rural area is an easiness index in measuring the manpower necessary for barrage construction. In general, sites far from village incur additional costs during the dam construction phase (Forzieri et al., 2008). On the basis of the literature, the layer was categorized into five classes.

Rainfall stations are dispersed all over the study area, thereby providing a means for the suitable estimation of rainfall distribution. Rainfall point measurements represent yearly values within 2000–2011. The Kriging interpolation method is employed to estimate rainfall in areas without rainfall point measurements (Chen et al., 2008). Eq. (1) was used to perform Kriging interpolation.

$$\hat{Z}(S_0) = \sum_{i=1}^n \lambda_i Z(S_i) \quad (1)$$

where, $Z(S_i)$ is the measured value, λ_i is an unknown weight for the measured value, $\hat{Z}(S_0)$ is the prediction value and n is the number of measured values.

The maximum and minimum amounts of rainfall can be found in the

northern and southern part of the study area respectively.

The study area has following characteristics: sand, gypsum, soils, gravel, stony and rough and rock protuberances (Buringh, 1960; Hameed, 2013). Fig. 5(a). Shows soil types of the study area. The study area is situated within the imbricate, high folded and low folded zone, and Zagros Suture Zone, all of which classified under the Unstable Shelf of the Arabian Plate (Sissakian, 2013; Sharbazheri et al., 2009). Fig. 5(b) represent the geological formation of the region.

The material for earth dam construction was extracted from the geological map. It is available at reasonable distances from the Greater Zab River, composed of loose gravel and clay materials, usable for the construction of an earth-fill dam body and of the impervious core, and suitable for the large-scale production of concrete aggregates. The construction materials should be available near the dam site to save transportation cost. This information can be obtained from the geological map. Shells needed for the construction of an earth-fill dam can be easily obtained from the abundant alluvial deposits present on the river bed and in the flood plain of the Greater Zab River and its tributary. The clay material was extracted from both layers of claystone comprising the Injana Formation and the old alluvial deposits found in the study area.

The abundance of loose gravel and sandy alluvial materials in the study area ensures the availability of inert materials necessary for the manufacture of high-quality concrete. The great quantity of sand within the flood plain deposits and the nearby beds of the wadis also help avoid any crushing processes for the production of fine and intermediate inert fractions.

Special structures of basin geology can be found in most parts of the Greater Zab basin. A site with fault lines along stream must be eliminated from listed potential dam sites (Forzieri et al., 2008). The dams must be located at least 100 m from the fault; this distance is used as a basis in rating areas with longer distance from the faults (Ghazal et al., 2015). The main Zagros Thrust Fault of the Zagros Suture Zone also runs within the extreme northern and northeastern part of the study area, causing the complicated structure framework of the involved area (Jabbar and Sissakian, 2010). Thus, areas near tectonic lines have lower inner layer weights compared with those far from tectonic lines (Lemos, 1988). Sites with faults and tectonic lines along streams must be eliminated from potential dam sites (Forzieri et al., 2008; Ameen, 1992).

The distance from road communications network is an important consideration when selecting dam sites. Dam sites should be near roads to reduce transportation cost (Ghazal et al., 2015). Water discharge is an important factor in dam site selection. Sites with a large amount of water discharge have high potential to be selected because they increase the hydropower of dams. The Kriging interpolation technique is used to map mean annual river discharges (Sauquet, 2006). In the present study, six discharge stations were used to interpolate the annual river discharge along the Greater Zab River.

Sub-criteria should be considered to realize a precise evaluation. From this concept, each main criterion in this study has sub-criteria (Table 1). All aforementioned main criteria and subcriteria were used to evaluate the suitable sites for dam construction.

3.2. AHP

AHP is a commonly used MCDM tool. AHP has been employed in a wide variety of applications in different fields, including site suitability (Drobne et al., 2009; Chakhar et al., 2003). Different factors have different levels of importance in potential dam site selection (Chezgi et al., 2016). Therefore, the importance of each parameter was identified. For instance, geology is the main consideration in dam site selection, but the level of importance of different geological factors varies. Geological formations are a more important consideration in dam site selection than the distance from a fault line. We have used a weighted linear combination in the present study (Drobne et al., 2009).

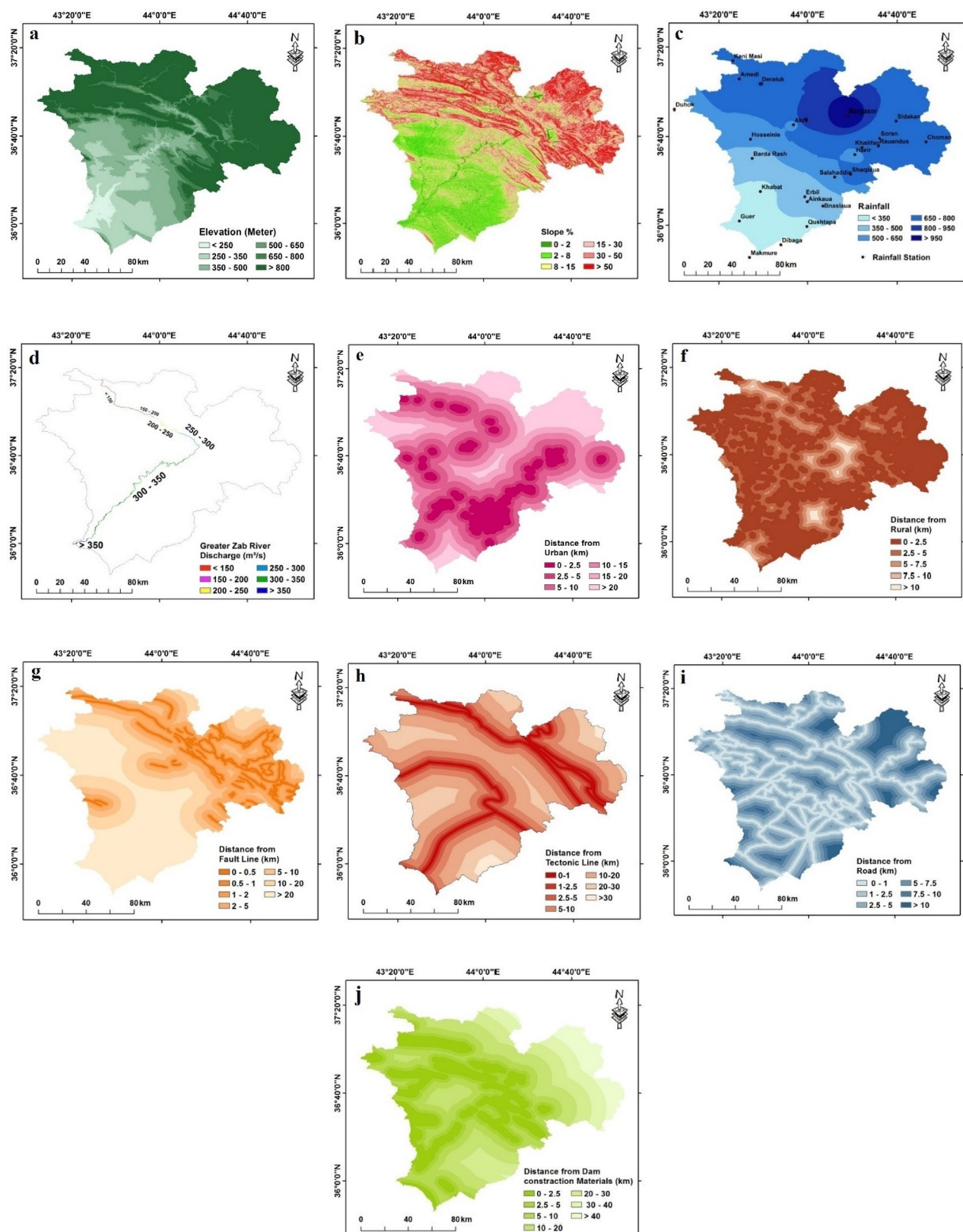


Fig. 3. Input thematic layers; (a) DEM; (b) Slope; (c) Rainfall; (d) Discharge; (e) Distance from urban; (f) Distance from rural; (g) Distance from fault line; (h) Distance from tectonic line; (i) Distance from road; and (j) Distance from construction material.

Step 1: Determination of weights

The relative importance of different criteria is a piece of important information for decision makers. MCDM is influenced by factors of different importance levels. Thus, the importance of each factor is

weighed and ranked in defining the decision maker's preferences (Drobne et al., 2009). An MCE module is used in weighing criteria. In this study, pairwise comparison or AHP developed by (Saaty, 1980) was used. Pairwise comparison compares each factor against all other

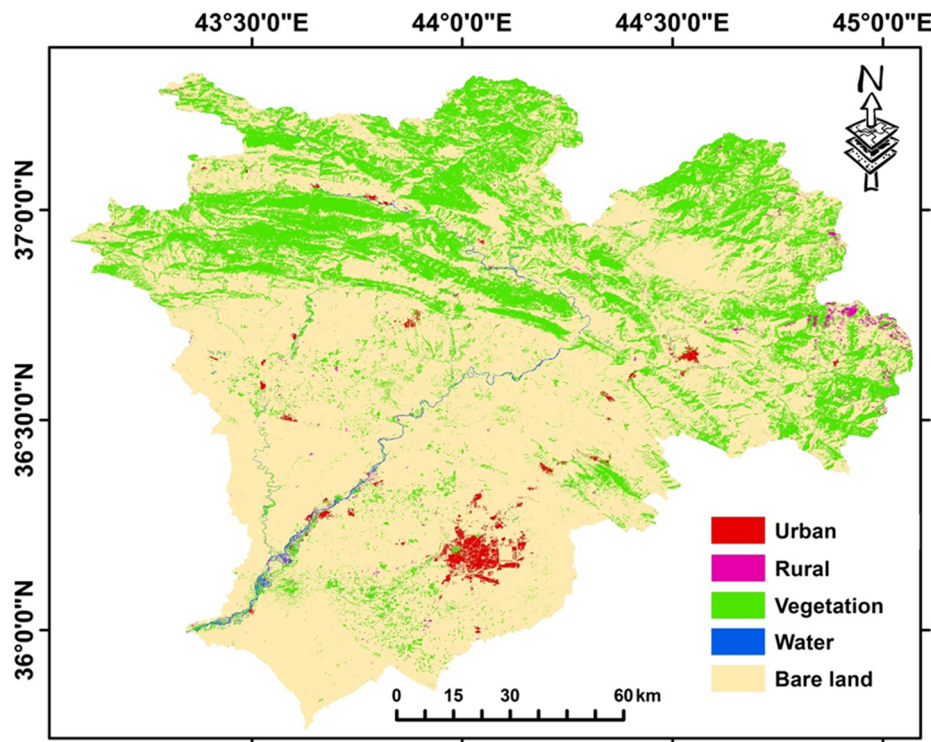


Fig. 4. Land Cover/Land Use map of the study area.

factors. To calculate the weights of factors in saaty's method, the main eigenvector of the square reciprocal matrix of pairwise comparison is employed between two criteria (Drobne et al., 2009). This method compares the importance of two criteria for a given object. Table 2 shows the explanation of the rating between two factors by nine points continuous scale (Drobne et al., 2009; Saaty, 1980).

Step 2: Pairwise comparison' consistency

Pairwise comparison' accuracy is measured by calculating the consistency ratio (CR) (Eq. (2)), which is used to evaluate the relative weight of each factor. The CR is a ratio between the Consistency index (CI) and the random index (RI). The comparison between criteria is acceptable when CR less than 10 %, otherwise, the CR lets for the re-evaluation of comparison

$$CR = \frac{CI}{RI} \quad (2)$$

Depending on the matrix order, the RI can be found from the specific table prepared by [53]. Table 3 shows RI value according to the number of factors.

The CI calculated using Eq. (3).

$$CI = \frac{\lambda_{max} - n}{n - 1}, \quad (3)$$

where

$$\lambda_{max} = (\text{Weight1} * S1 + \text{Weight2} * S2 + \text{Weight3} * S3 + \dots)$$

n = number of criteria

After calculating the CI, the CR equation is applied. If the result is less than 10%, then the weight was assigned.

Step 3: Geometric mean

The geometric mean is a special type of average where the numbers are multiplied as percentages derived from values together and then -root is applied for the numbers as described in Eq. (4) (Dong et al., 2010).

$$\text{Geometric Mean (G. M)} = \sqrt[n]{X1 * X2 * X3 \dots Xn} \quad (4)$$

where n represents the number of returns in the series, and X is a variable.

In this research, the geometric mean formula was used after collecting the questionnaire related to the AHP matrices from six expert's feedback questionnaires. The geometric mean was calculated for each factor from the matrices with CRs less than 10%. Table 4 shows the geometric mean for the final weight for each main criterion. Table 5 shows the final weightage of criteria. Furthermore, the geometric mean formula was applied for sub-criteria.

3.3. Application of the fuzzy logic model

Zadeh (1965) proposed Fuzzy logic based on fuzzy set theory. The fuzzy approach is applied in land suitability mapping where pixels on any causal factor layer are considered a suitable area. Pixel values could range from 0 (i.e., not suitable) to 1 (i.e., suitable). Pixel values must lie in the range of 0 to 1, but the choice of values has no practical constraint. The values reflect the degree of membership of a set according to subjective judgment (Bonham, 1994) or can be derived by various functions representing the reality (in this study, the linear functions are used) (Eastman, 2003). In the present case, fuzzy membership values were assigned as recommended by (Saaty, 1980) Table 2. Fuzzy logic is preferred for land suitability evaluation because fuzzy approaches estimate land use suitability on a continuous scale (Elaalem, 2012). Tables 6 and 7 show the relative importance of the factors according to the class interval and class type, respectively. Land suitability based on fuzzy logic helps overcome vagueness and uncertainty. The application of fuzzy logic in site suitability evaluation has four steps (Elaalem, 2012).

Step 1: Normalization or standardization of land characteristics using fuzzy set models

Fuzzy logic membership helps in determining the suitability or unsuitability of a site. This step assigns values from 0 (i.e., not likely or unsuitable) to 1 (i.e., most likely or suitable) (Elaalem, 2012). Thus, higher fuzzy membership value means better site suitability. Understanding the four types of membership and choosing the one that best fits the analysis criteria are important when assigning fuzzy membership values. The membership function in a fuzzy system has several

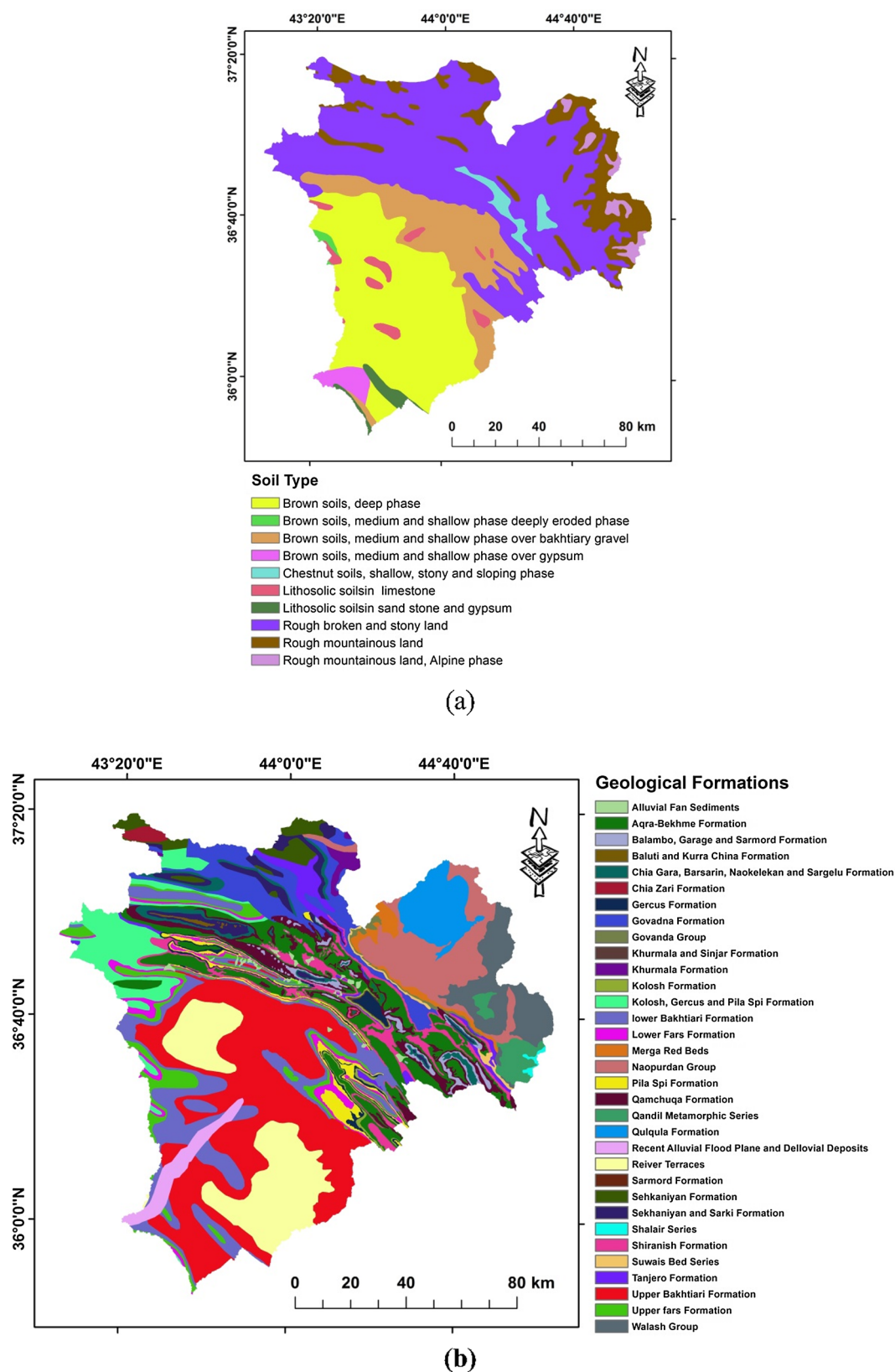


Fig. 5. (a) Soil type; and (b) Geological formation.

types, such as linear, small, large, and Gaussian. In this study, the linear membership function is used to normalize the parameters because it depends on input parameters. If the input parameters are chaotic (e.g., time series), the Gaussian type of membership function is suggested;

otherwise, the linear type is recommended (Qiu et al., 2014). Large or small values are assigned with high fuzzy membership; fuzzy membership decreases at a constant rate.

A triangular membership function is specified by the following three

Table 1
Sub-criteria factors extracted from main criteria.

No	Main Criteria	Sub-criteria
1	C1) Geology	C1-1) Geological Formations C1-2) Soil type C1-3) Distance from Fault line C1-4) Distance from Tectonic line
2	C2) Topography	C2-1) Slope C2-2) Elevation
3	C3) Hydrology	C3-1) Annual Rainfall C3-2) River discharge
4	C4) Economic	C4-1) Distance from Dam construction material C4-2) Distance from Urban C4-3) Distance from Rural C4-4) Distance from Road

Table 2
The weight of relative importance adopted from (Drobne et al., 2009) (Saaty et al., 1977).

Intensity of Importance	Definition
1	Equal Importance
2	Equal to moderate Importance
3	Moderate Importance
4	Moderate to strong Importance
5	Strong Importance
6	Strong to very strong Importance
7	Very strong Importance
8	Very to extremely strong Importance
9	Extremely Importance

Table 3
Average random consistency index (RI) (adopted from Drobne et al., 2009).

Number of criteria	2	3	4	5	6	7	8
Random Index	0.00	0.58	0.90	1.12	1.24	1.32	1.41

Table 4
Applying the geometric mean formula for each main criteria weight of six questionnaires.

Criteria	AHP Weights from questionnaire						Applying G.M
	1	2	3	4	5	6	
Geology	0.591	0.456	0.406	0.542	0.574	0.541	0.514
Topography	0.199	0.303	0.311	0.233	0.222	0.223	0.245
Hydrology	0.140	0.146	0.182	0.140	0.126	0.152	0.147
Economy	0.069	0.094	0.100	0.085	0.077	0.084	0.085
CR	4.8%	3%	3.6%	1.9%	1.3%	4.4%	
CI	4.3%	2.7%	3.2%	1.7%	1.1%	3.9%	

Table 5
Final weightage of criteria.

Criteria	Weightage
Geology formation	0.289
Soil	0.131
Tectonic	0.056
Fault	0.036
Material	0.044
Urban	0.021
Rural	0.015
Road	0.006
Slope	0.169
Elevation	0.074
Rainfall	0.047
Discharge	0.100

parameters {a, b, c}:

$$\text{Triangulation}(x; a, b, c) = \begin{cases} 0, & x \leq a \\ \frac{(x-a)}{(b-a)}, & a \leq x \leq b \\ \frac{(c-x)}{(c-b)}, & b \leq x \leq c \\ 0, & c \leq x \end{cases} \quad (5)$$

Step 2: Generation of the criterion map layers

In fuzzy logic, an alternative scaling approach where linguistic variables represent both quantitative and qualitative criteria is offered. The study by (Marks et al., 1995) provides an example of a qualitative variable that is expressed as a linguistic variable. In a quantitative criterion (e.g., return on resources), the terms “very low,” “low,” “medium,” “high,” and “very high” should be defined for representation by a linguistic variable. These terms are represented by fuzzy sets that are defined on the present quantitative scale.

In this study, the linear membership function was used to normalize the parameters because it depends on input parameters; if the input parameter is not chaotic, the linear membership function is suggested (Elaalem, 2012). This step assigns values from 0 (i.e., not likely or unsuitable) to 1 (i.e., most likely or suitable). The range between 0 to 1 membership function corresponds to the intensity of importance of each criterion, which is determined on the basis of the literature and expert opinion.

Step 3: Generation of the overall land suitability map layers

Several reclassified surfaces with values ranging from 0 to 1 are generated by assigning the appropriate fuzzy membership value for data criteria (Clinton et al., 2010). In the next step, the fuzzy logic model is applied. This step is similar to weighted site selection, a site selection type that allows users to rank Raster cells and assign a relative importance value to each layer because it compares the different reclassified surfaces. This step is completed by selecting a type of fuzzy overlay. The Boolean operations were used to integrate all factors by logical operators such as AND and OR operations. AND is intersection operator and it is a very restrictive or risk-averse operator. The mission of AND distinguish because of an area will be excluded from the suitability maps if any single criteria fails to meet its threshold. On the other hand, OR is a union operator, in which, there is a risk involved and an entire area could be chosen as long as a single criterion meets its threshold (Romano et al., 2015). In this study, “AND” fuzzy overlay type is used because of its suitability for finding locations that meet all criteria (Qiu et al., 2014; Cheng and Thompson, 2016).

3.4. Accuracy assessment

To evaluate the results obtained from the AHP and fuzzy models, a segmentation accuracy assessment was used and modified for dam site selection (Clinton et al., 2010). The method is based on the number of suitable pixels (i.e. segment) identified by the model and the summation of distances from suitable pixels to the reference point. First, the reference point was identified and located on the map of the suitable site for dam construction as determined by experts (i.e., The proposed dam is Bekhme dam). Then, three buffers with distances of 250, 500, and 1000 m were created around the reference point. Spatial tools in GIS were used to estimate the statistics of the suitable pixels inside these buffers (i.e., the total number of pixels, the number of suitable pixels and distance from the pixels to the reference point). These statistics then were used to calculate the two-accuracy measurement, which is described by Eq. (6):

$$\text{Accuracy of suitable pixels} = \frac{n}{\sum n} \% \quad (6)$$

n : Number of high suitable pixels

Table 6
Relative importance of factors according to the class interval.

Factor	Interval	Intensity of important	Factor	Interval	Intensity of important
Distance from Tectonic line (km)	< 1	1	Distance from Road (km)	< 1	9.0
	1–2.5	2		1–2.5	8.0
	2.5–5	3		2.5–5	7.0
	5–10	6		5–7.5	5.0
	10–20	7		7.5–10	3.0
	20–30	8		> 10	1.0
	> 30	9			
Distance from Fault line (km)	< 0.5	1	Slope Interval (percent)	< 2	5
	0.5–1	2		2–8	9
	1–2	3		8–15	6
	2–5	6		15–30	4
	5–10	7		30–45	2
	10–20	8		> 45	1.0
	> 20	9			
Distance from construction materials (km)	< 2.5	9	Elevation Interval (m)	180–250	1
	2.5–5	8		250–350	4
	5–10	7		350–500	8
	10–20	5		500–650	9
	20–30	3		650–800	4
	30–40	2		> 800	1
	> 40	1	Rainfall Interval (mm)	> 350	1
Distance from Urban area (km)	< 2.5	1		350–500	3
	2.5–5	6		500–650	5
	5–10	9		650–800	6
	10–15	7		800–950	7
	15–20	4		> 950	9
	> 20	1	Discharge Interval (m ³ /s)	< 150	1.0
Distance from Rural area (km)	< 2.5	1		150–200	3.0
	2.5–5	6		200–250	5.0
	5–7.5	9		250–300	6.0
	7.5–10	8		300–350	7.0
	> 10	1		> 350	9.0

Table 7
Relative importance according to the class type.

Factor	Class type	Intensity of important	Factor	Class type	Intensity of important
Geological formation	Upper Bakhtiari Formation	5	Soil Type	Lithosolic soilsin sand stone and gypsum	1
	lower Bakhtiari Formation	5.3		Lithosolic soilsin limestone	6
	Upper fars Formation	5.5		Brown soils, medium and shallow phase over bakhtiari gravel	3.5
	Lower Fars Formation	2		Brown soils, medium and shallow phase over gypsum	2
	Pila Spi Formation	6.2		Brown soils, medium and shallow phase deeply eroded phase	4
	Gercus Formatio40n	6		Brown soils, deep phase	5
	Khurmala and Sinjar Formation	6.3		Chestnut soils, shallow, stony and sloping phase	4.5
	Kolosh Formation	3.5		Rough broken and stony land	6
	Kolosh, Gercus and Pila Spi Formation	4.2		Rough mountainous land	7
	Tanjero Formation	4		Rough mountainous land, Alpine phase	9
	Shiranish Formation	5.4			
	Aqra-Bekhme Formation	8.5			
	Qamchuqa Formation	9			
	Sarmord Formation	6.5			
	Balambo, Garage and Sarmord Formation	6.8			
	Chia Gara, Barsarin, Naokelekan and Sargelu Formation	8			
	Sekhanyan and Sarki Formation	8.2			
	Baluti and Kurra China Formation	6.4			
	Recent Alluvial Flood Plane and Dellovial Deposits	1			

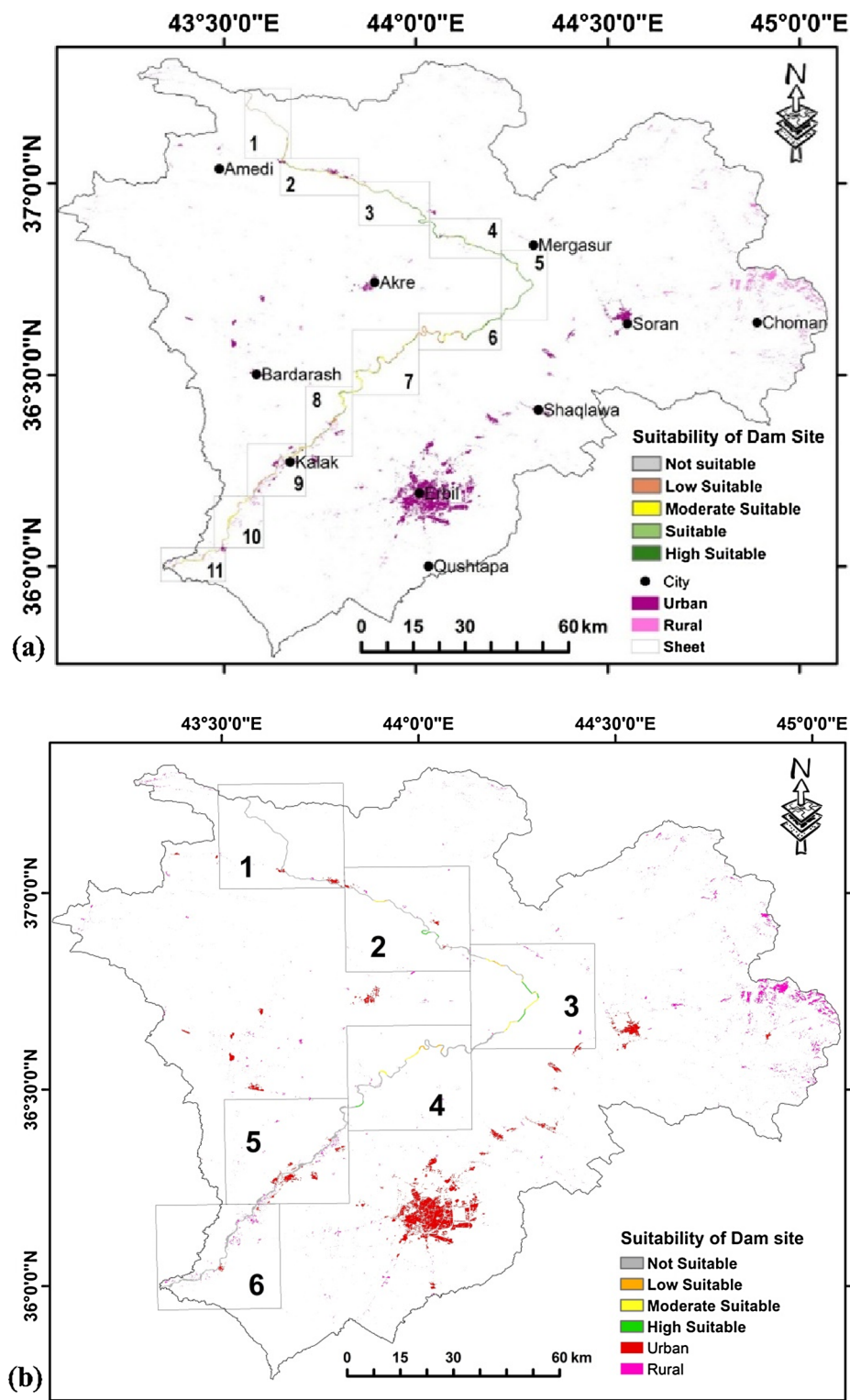


Fig. 6. Potential suitability map of dam site selection by (a) AHP; and (b) Fuzzy logic.

$$\text{Accuracy of distance from reference} = \frac{\text{max} - \text{distance from reference}}{\text{max} - \text{min}} \quad (7)$$

$$\begin{aligned} \text{Overall accuracy} \\ = \frac{(\text{accuracy of suitable pixels} + \text{accuracy of distance from reference})}{2} \end{aligned} \quad (8)$$

First, the accuracy of suitable pixels was calculated using the number of suitable pixels found in each buffer to the total number of pixels contained in the buffer area. Then, the accuracy of distances from suitable pixels to the reference points (i.e. Bekhme Dam) was estimated using Eq. (7), which required the maximum and minimum distances from suitable pixels to the reference point in both models. Based on these two accuracy measures, the overall accuracy was calculated using Eq. (8).

Table 8
The overall accuracy of site suitability using AHP and fuzzy models.

Fuzzy	No. of pixel	$\sum n$	Sum Distance	Accuracy of suitable pixels	Accuracy of distance from reference	Overall accuracy
250 m	66	101	8749.61	65%	99%	82%
500 m	147	219	37332.41	67%	75%	71%
1000 m	251	452	114626.42	56%	9%	32%
AHP	n	$\sum n$	Sum Distance	Accuracy of suitable pixels	Accuracy of distance from reference	Overall accuracy
250 m	60	101	7631.45	59%	100%	80%
500 m	140	219	37997.82	64%	74%	69%
1000 m	262	452	124786.66	58%	0%	29%
			max = 124786.66			
			min = 7631.45			

4. Results and discussion

4.1. Identification of suitable sites for dams by the AHP model

After setting the conditioning factors in GIS, questionnaires were prepared for experts based on the factors determined, and their classes were identified from the literature review. The experts provided feedback about the factors and their contribution in selecting suitable sites for dam construction in the study area. Then, the weights of each factor were calculated using the geometric mean method in GIS to determine the final weight of each factor. The factors were then reclassified based on their weights and prepared using the Raster calculator to generate a suitability map that describes the locations for constructing dams.

The suitability map produced using the AHP model is shown in Fig. 6(a). This map shows the suitable areas in green color and non-suitable areas in gray color. The suitable areas were almost distributed in the entire study area. However, the most suitable areas were found in the middle of the study area. The overall area of highly suitable lands for constructing dams was 13,446,900 m². Therefore, a field visit is required to identify the final location of the dams. The suitability map produced in GIS by the AHP model shows that suitable sites are not clustered in a single area but distributed into different locations in the study area. The finding indicates that some of the conditioning factors largely influence the selection of suitable sites and are distributed in the study area and not clustered. The final weights of factors show that the geology formation was the most influenced factor for dam site suitability while the distance from road factor has the lowest influence on dam site suitability (Table 5). This is because AHP uses the weights of these factors ultimately leading to higher weightage. Only some of the sites identified as suitable by the AHP model were near urban areas. These sites needed further investigations and analysis to determine their possibility of constructing dams.

4.2. Application of fuzzy model

The suitability map produced by the fuzzy method is presented in Fig. 6(b). This map shows the locations of suitable and non-suitable areas for dam construction in the study areas. The map shows that most of the suitable areas are in the middle and north parts of the study area. The southern part of the study area contains no suitable sites for dam construction and thus should be ignored in the field visit. The overall surface area of the highly suitable lands is estimated to be 3,409,200 m². These results indicate that the middle part of the study area is suitable for the first suitable location of dams. However, field visit is required to confirm the final location for dam construction. Field visit enables the selection of the best locations in consideration of other factors (e.g., population) that are not used in the model and may change.

The suitability map produced by the fuzzy model shows the spatial distribution of the suitable areas and their patterns in the study area. Most of the suitable areas are clustered into groups and are not randomly scattered into different directions. This finding indicates that

suitable areas determined to have the same characteristics and are homogenous. This information makes the final selection of decision makers easier and more accurate. In other words, a decision maker can easily identify the suitable areas for dam construction. Decision makers also need to view the suitable locations in the field to determine the final sites for dam construction. This procedure is important because changes may occur in the sites and because other factors, such as the need for the hydropower or the amount of irrigation water, are not considered in the model.

4.3. Models comparison

In this study, two models such as AHP and Fuzzy logic were used. AHP was used because of its proven benefits in decision making that can be obtained through pairwise comparison. On the other hand, Fuzzy approach was used because of its ability to omit the crisp boundaries in the modeling process. In terms of the surface area of the suitable lands identified, the AHP model produced 13,446,900 m² as highly suitable area, whereas the fuzzy model identified 3,409,200 m² area as highly suitable for constructing dams. This result indicates that the results generated by the fuzzy model are more reasonable and accurate than the results generated by the AHP model. This result can be ascribed to the fact that fuzzy analysis models the uncertainties in the layers used. In the AHP model, the hard boundaries between the factors and within each class of each factor are directly modeled. This result is also consistent with previous results that fuzzy could produce better results than AHP. The nature of the fuzzy system and its dealing with uncertainties between class boundaries render this approach more logical than the AHP approach. In addition, the fuzzy approach does not require specific weights for each class and thus produces results that are not biased toward one factor. This characteristic is obvious in the AHP model in that the results are more distributed and scattered in the whole study area, which indicates the absence of bias toward certain factors and almost to the geology factor (has the highest weight among the factors). The accuracy of the results produced from both models is presented in the next section.

4.4. Accuracy assessment

Table 8 shows the overall accuracy of site suitability determined by the AHP and fuzzy models. The overall accuracies indicate that the fuzzy model is more accurate than the AHP model and that it is consistent in the three buffers (Fig. 7(a)). This finding ensures that the fuzzy model produces a suitability map that is more accurate than AHP based on the location of the reference point. The accuracy assessment mechanism evaluates the performance of AHP by using three buffering zones with varying distances to calculate the distance from suitable pixels to the reference point (i.e. Bekhm Dam) as illustrated in Fig. 7(b). On the other hand, the results of AHP method demonstrated that the number of pixels are scattered and spread in different regions (Fig. 7(b)). On the contrary, the pixels in Fuzzy model are mostly clustered.

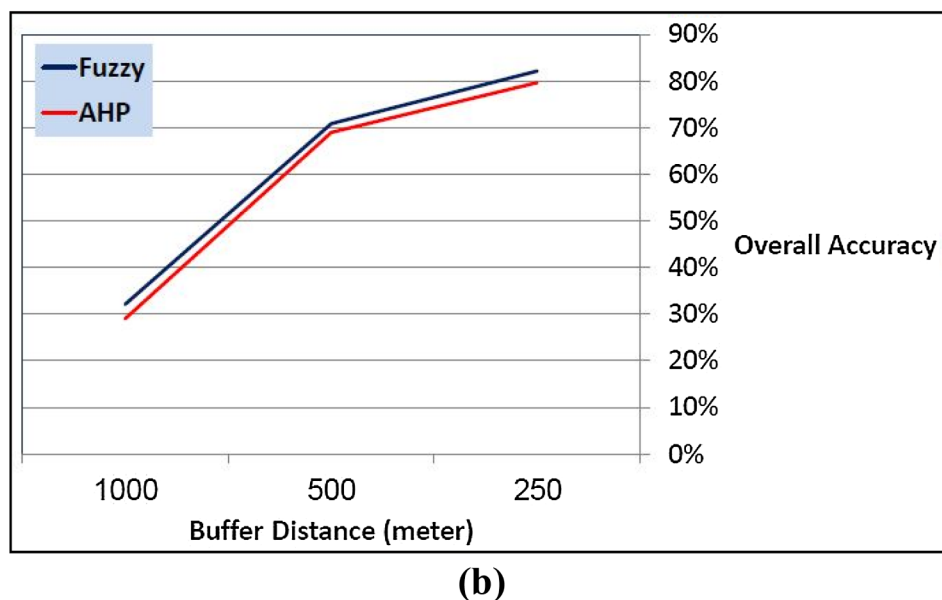
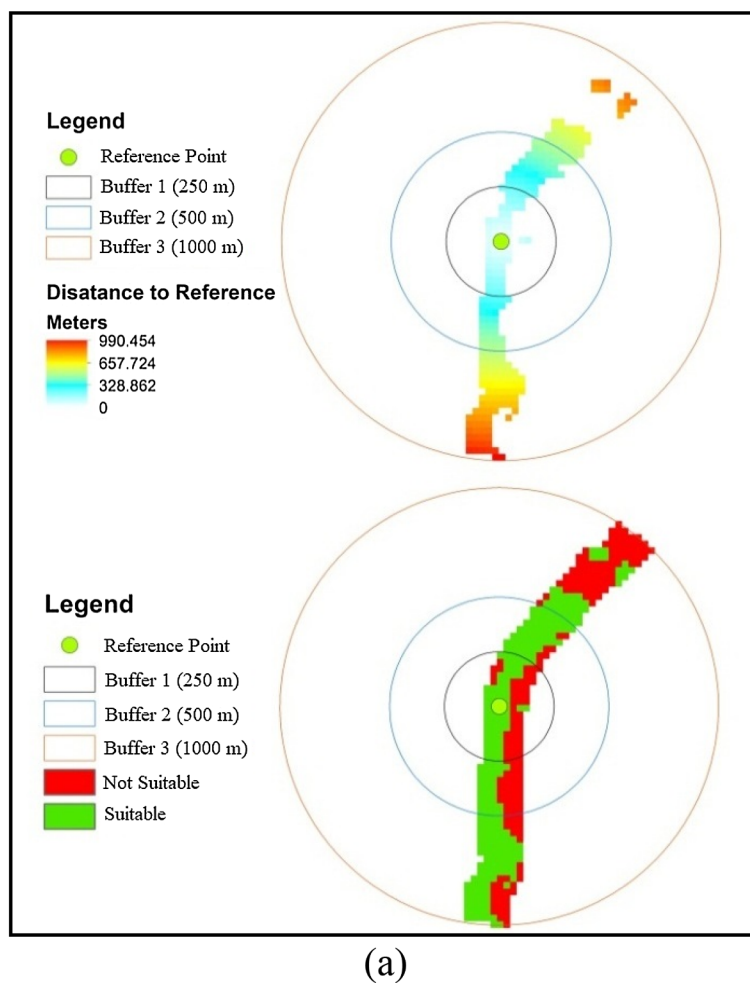


Fig. 7. (a) Accuracy assessment mechanism of AHP; (b) The overall accuracy of AHP and fuzzy logic graph.

4.5. Characteristics of proposed dams

On the basis of the suitability maps of dam location obtained from the fuzzy model, the layers of drainage network, contour line and triangulated irregular network (TIN) were generated from ASTER Digital Elevation Model. In this research, the proposed dams are medium and

large sized. Dam location was selected in accordance with the site suitability of dam layer that obtained from fuzzy model. In addition, the height and volume were calculated from the TIN using 3D spatial tools of ArcGIS software. Dam's length was computed from the section dam profile which is extracted from the Digital Elevation Model using ArcGIS 3D spatial tools. The location and number of proposed dams in

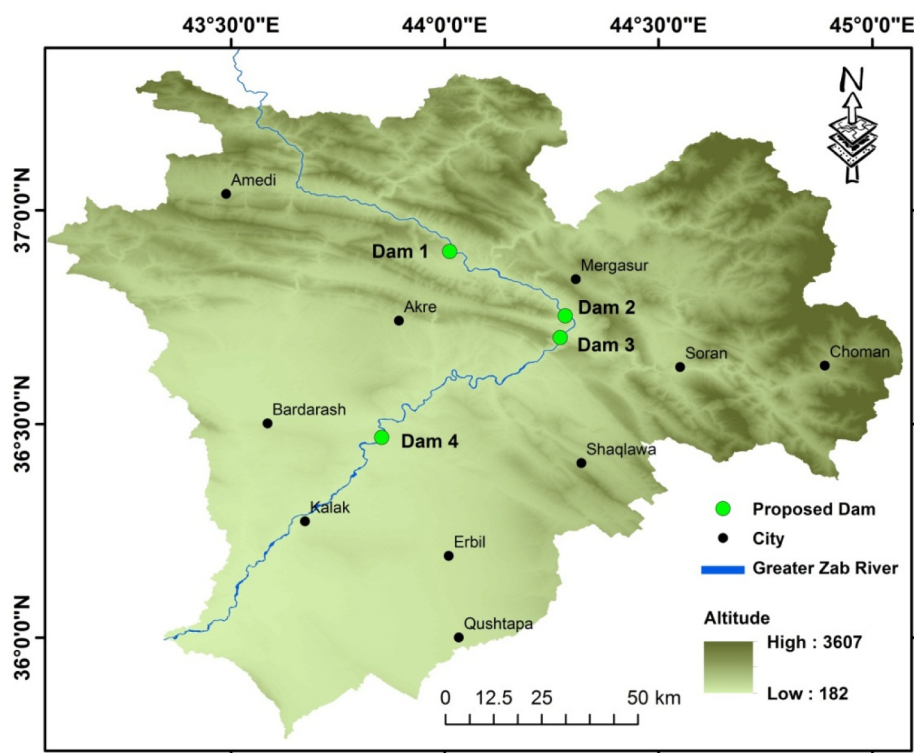


Fig. 8. Location of proposed dams (dam 1 to dam 4) in the study area.

Table 9

Size classification of dams from Robinson, 2006.

Category	Storage (m ³)	Height (meter)
Small Dam	< 1,234,000 and $\geq 61,600$	< 12.5 and ≥ 5
Intermediate Dam	$\geq 1,234,000$ and < 61,675,000	≥ 12.5 and < 30.5
Large Dam	$\geq 61,675,000$	≥ 30.5

the study area are presented in Fig. 8. The dams should be located on the water drainage. The southern part of the study area has gentle slopes which are plan with depthless water drainage. By contrast, the northern part is almost mountains and hilly with the deep water drainage.

Dam 1 is situated upstream of the drainage. Dam 1, 2, 3 and 4 are located successively according to the order of the drainage. A site with narrow drainage is preferred to minimize the structures' cost. Sites of the dam should be located in a way that the water can be controlled over a monsoon. Dams may be situated near habitation. The water in dams reservoirs could either be used for irrigate surrounding areas or transmit to the southern part of the study area through the water drainage network to provide additional irrigation during drought.

Proposed sites for dam construction were obtained from the suitability map with medium and large size. The height, length, storage capacity, and basin area of the selected dams were considered. Appropriate locations for the dams were searched using drainage networks and contour lines per 5 m interval. The storage capacity of the dam was estimated using the triangular irregular network layer via ArcGIS 10.3 tools. The factors that effects dam size are storage capacity and height of dam (Robinson, 2006). Table 9 shows that dams can be classified as small, medium, or large. The present study identified only intermediate and large potential dams. Table 9 illustrates the different types of dam according to size and height. The storage capacity of Dam 1, 2, 3, 4 are shown in Fig. 9.

Table 10 illustrates the geometric characteristics of the proposed dam sites. Dam 1 is located at 36° 54'15" N, 44° 00' 42" E with an

elevation of 490 meters above sea level. Dam 2 is located at 36° 45' 11" N, 44° 16' 53" E with an elevation of 400 meters. Dam 3 is located at 36° 42' 08" N, 44° 16' 11" E with an elevation of 500 meters.

Dam 4 is situated at 36° 27' 59" N, 43° 51' 30" E with an elevation of 290 meters and the storage capacity around 646.5 million m³ at the height of 60 m. The location of dams 1, 2, 3 and 4 were selected in highly suitable areas for constructing dams. Among the four dams, Dam 4 can store the largest amount of water. The storage capacity of Dam 4 is 646.5 million m³ at 60 m height of the dam proposed by a group of experts in 1988 (Table 10). Dam 3 has the shortest length among the four dams-which making it more economic than the others. Fig. 9 shows the storage volumetric capacity of Dam 1, 2, 3 and 4. Table 10 shows the capacity of the reservoirs and their elevations of Dam heights for Dam 1, 2, 3 and 4. The suitable area for dam construction in the Greater Zab Basin was estimated from the available data. However, other criteria, such as population and socioeconomic status, should be considered; but, these criteria were unavailable for use in this study. Finally, the ranking of dam sites were done according to length, storage capacity, and cost i.e. Dam 3 is the first and the second, third and fourth were Dam 4, Dam 1 and Dam 2 respectively.

4.6 Discussion In recent decades, the application of remote sensing and GIS techniques are very popular in hydrology. Remote sensing based techniques provide valuable datasets to examine hydrological variables and morphological changes over large regions at different spatial and temporal scales (e.g. ASTER DEM satellite image). Therefore, by using the capability of remote sensing and GIS technology to prepare a detailed hydrological impact analysis of the proposed dam sites to play a vital role in the analysis of any watersheds. Therefore, the remote sensing contributed to providing a way of compiling data in less time, overcoming some old problems (difficult access, the uncertainty of subjectivity) that hamper mapping georeferenced features with greater precision in a more effective way. Furthermore, suitability of dam site contributes to the upgrading of hydrological variables including surface and groundwater storage area for flood control, power requirements, irrigation, water supply, rainfall, runoff, evaporation.

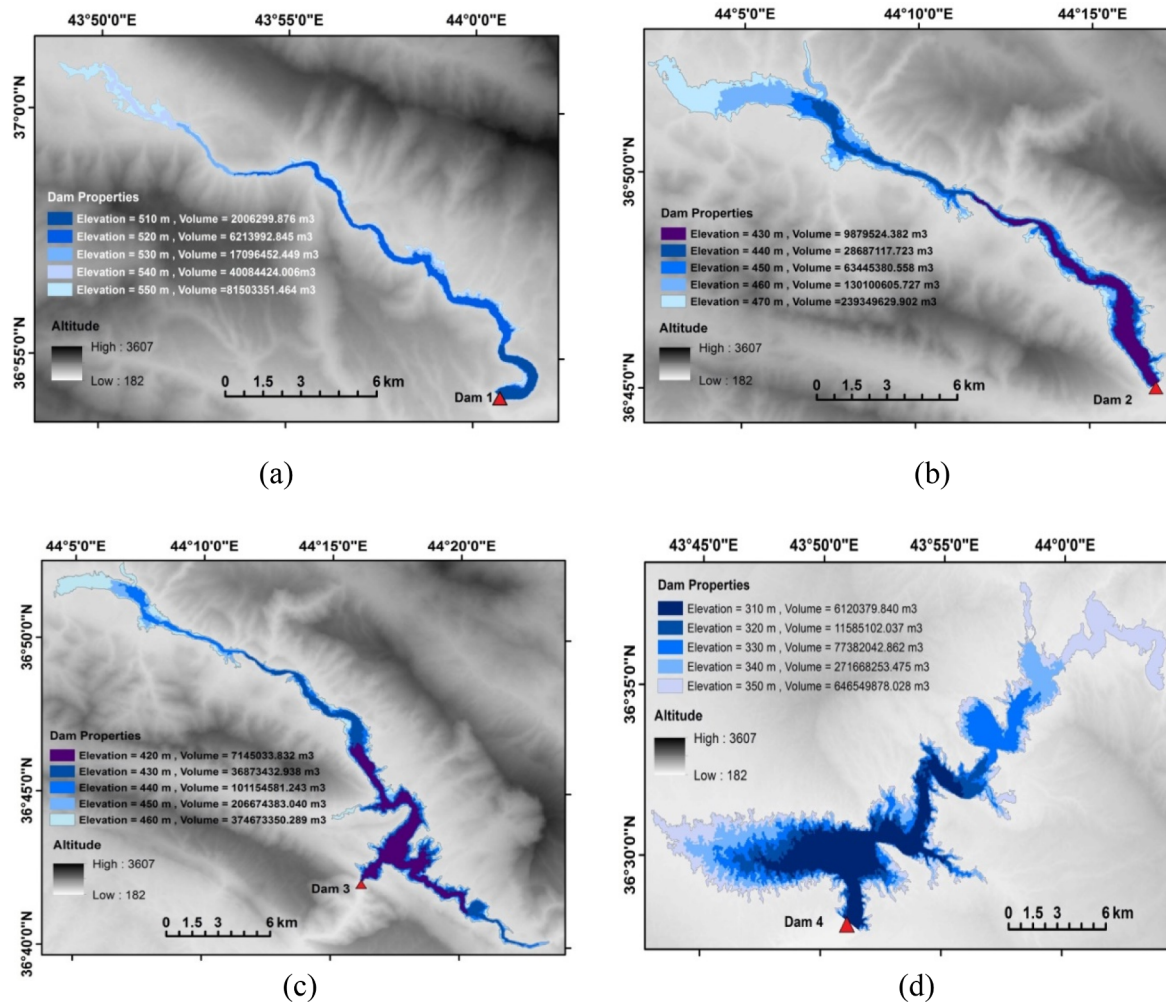


Fig. 9. The storage capacity of (a) Dam 1; (b) Dam 2; (c) Dam 3; and (d) Dam 4.

Table 10
Geometric characteristics of the proposed dam sites.

Proposed dams	Elevation (m)	Dam height (m)	Dam length (m)	Storage volumetric capacity m ³
Dam 1	510	20	386	2,006,299
	520	30	428	6,213,992
	530	40	474	17,096,452
	540	50	510	40,084,424
	550	60	563	81,503,351
Dam 2	430	20	423	9,879,524
	440	30	472	28,687,117
	450	40	510	63,445,380
	460	50	570	130,100,605
	470	60	628	239,349,629
Dam 3	420	20	100	7,145,033
	430	30	122	36,873,432
	440	40	153	101,154,581
	450	50	200	206,674,383
	460	60	234	374,673,350
Dam 4	310	20	1,130	6,120,379
	320	30	1,500	11,585,102
	330	40	1,595	77,382,042
	340	50	1,705	271,668,253
	350	60	1,848	646,549,878

It is important to compare the results of both the models (AHP and Fuzzy) for dam site suitability in order to identify the similarities and differences. If we compare both maps produced by AHP and Fuzzy, it is clear that maps produced by AHP show the suitable area as scattered

regions, whereas the fuzzy model showed clustered areas as suitable. In the map produced by AHP, one can observe that the suitable areas can be found almost in all parts of the study area. This could be attributed due to the benefits obtained through pairwise comparison. Whereas, in the map produced by Fuzzy logic, the suitable areas are only found in the middle part and some parts in the north of the study area. This can be explained as the Fuzzy logic approach is suitable for spatial and natural phenomena because of omitting the crisp boundaries. In addition, it is obvious to observe that the fuzzy model generated results more accurate and logical than the AHP model. The reason for this could be because the fuzzy analysis modelled the uncertainties in the layers used. In the AHP model, the hard boundaries between the factors and within each class of each factor are directly modelled. This is consistent with the literature wherein researchers have indicated that fuzzy logic could produce better results than the AHP. The nature of the fuzzy system and its dealing with uncertainty between the classes boundaries made this approach more logical than the AHP approach.

5. Conclusion

Finding a suitable location for dam construction is important. Remote sensing and GIS are popular tools used for such purposes. Remote sensing provides data about the study area, whereas GIS merits spatial analysis and modeling for producing suitability sites. A method to evaluate the conditioning factors contributing to the suitability level of a dam location is required. In the literature, decision making based on AHP and fuzzy logic are commonly used. In this study, the

conditioning factors of dam suitability were generated from various types of remote sensing and field data. Then, both AHP and fuzzy logic-based decision making were applied. The weights resulting from the decision-making models were used in GIS, and suitability maps were produced. The AHP model produced 13,446,900 m² as highly suitable area, whereas the fuzzy model identified 3,409,200 m² as a highly suitable area for constructing dams from the total area of 69,347,700 m². This finding is obvious in the AHP model, and the results are more distributed and scattered in the whole study area. This outcome indicates that this model is unbiased toward certain factors and almost to the geology factor (has the highest weight among the factors). Conversely, the fuzzy model showed the suitable area as clustered areas. Both models were then evaluated and compared using a new technique. The overall accuracy rates of AHP for three buffers with distances of 250, 500, and 1000 m around the reference point were 80%, 69%, and 29%, whereas those of fuzzy were 82%, 71%, and 32%, respectively. The overall accuracies indicate that the fuzzy logic is more accurate than AHP model, and this finding is consistent with the three buffers. Finally, the final dams located in the study area were characterized using the digital elevation model gathered from the ASTER sensor. The location of 1st Dam, 2nd Dam, 3rd Dam and 4th Dam were selected in highly suitable areas for constructing dams, and the 4th dam was deemed the best site for water harvesting. Among the four dams, Dam 4 can store the largest amount of water. The storage capacity of Dam 4 is 646.5 million m³ at 60 m height, whereas that of Dam 3 is only 374.6 million m³ at 60 m height of the dam proposed by a group of experts in 1988. Dam 3 has the shortest length among the four dams, making it more economic than the others. This study attempted to apply and compare two different approaches (fuzzy logic and AHP) for dam site suitability assessment. The result of this research can provide some guidelines for other researchers in this field and it will be easy for them to select the most suitable approach for dam site selection. Dam site selection can be realized by using either AHP or fuzzy models with or without weights. This method increases the efficiency and flexibility of the proposed decision-making tools. Using GIS tools are the effective way for decision making of dam site selection.

Conflicts of interest

The authors declare no conflict of interest.

Acknowledgements

Authors would like to thank two anonymous reviewers for their valuable comments which helped us to improve the earlier version of the manuscript. This research is funded by the Centre for Advanced Modelling and Geospatial Information Systems (CAMGIS) at the University of Technology Sydney (UTS) under grant numbers 323930, 321740.2232335 and 321740.2232357.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jhydrol.2019.05.001>.

References

- Abdulkareem, J.H., Sulaiman, W.N.A., Pradhan, B., Jamil, N.R., 2018a. Long-term hydrologic impact assessment of nonpoint source pollution measured through land use/land cover (LULC) changes in a tropical complex catchment. *Earth Syst. Environ.* 2 (1), 67–84. <https://doi.org/10.1007/s41748-018-0042-1>.
- Abdulkareem, J.H., Pradhan, B., Sulaiman, W.N.A., Jamil, B.R., 2018b. Quantification of runoff as influenced by morphometric characteristics in a rural complex catchment. *Earth Syst. Environ.* 2 (1), 145–162. <https://doi.org/10.1007/s41748-018-0043-0>.
- Abdullahi, S., Mahmud, A.R.B., Pradhan, B., 2014. Spatial modelling of site suitability assessment for hospitals using geographical information system-based multicriteria approach at Qazvin city, Iran. *Geocarto Int.* 29 (2), 164–184.
- Abushandi, E., Alatawi, S., 2015. Dam site selection using remote sensing techniques and geographical information system to control flood events in Tabuk City. *Hydrol. Current Res.* 6, 189.
- Ahamed, T.N., Rao, K.G., Murthy, J.S.R., 2000. GIS-based fuzzy membership model for crop-land suitability analysis. *Agr. Syst.* 63 (2), 75–95.
- Ahmad, S.R., Ahmad, U., Masood, A., 2013. Geo-spatial techniques in selection of potential damsite. *Pakistan J. Sci.* 65 (1).
- Ajaj, Q.M., Pradhan, B., Noori, A.M., Jebur, M.N., 2017. Spatial monitoring of desertification extent in Western Iraq using Landsat Images and GIS. *Land Degrad. Dev.* 28 (8), 2418–2431.
- Al-Ansari, N., Ali, A., Knutsson, S., 2014. Present conditions and future challenges of water resources problems in Iraq. *J. Water Resour. Prot.* 6 (12), 1066–1098.
- Altinbilek, D., 2002. The role of dams in development. *Int. J. Water Resour. D.* 18 (1), 9–24.
- Althuwaynee, O.F., Pradhan, B., Lee, S., 2012. Application of an evidential belief function model in landslide susceptibility mapping. *Comput. Geosci.* 44, 120–135.
- Althuwaynee, O.F., Pradhan, B., Park, H.J., Lee, J.H., 2014. A novel ensemble bivariate statistical evidential belief function with knowledge-based analytical hierarchy process and multivariate statistical logistic regression for landslide susceptibility mapping. *Catena* 114, 21–36.
- Ameen, M.S., 1992. Effect of basement tectonics on hydrocarbon generation, migration, and accumulation in Northern Iraq (1). *AAPG Bull.* 76 (3), 356–370.
- Awchi, T.A., 2014. River discharges forecasting in northern Iraq using different ANN techniques. *Water Resour. Manag.* 28 (3), 801–814.
- Bonham-Carter, G.F., 1994. Geographic information systems for geoscientists-modeling with GIS. *Comput. Methods Geoscientists* 13, 398.
- Buringh, P., 1960. Soils and soil conditions in Iraq. Ministry of agriculture.
- Burrough, P.A., MacMillan, R.A., Van Deursen, W., 1992. Fuzzy classification methods for determining land suitability from soil profile observations and topography. *J. Soil Sci.* 43 (2), 193–210.
- Chakhar, S., Martel, J.M., 2003. Enhancing geographical information systems capabilities with multi-criteria evaluation functions. *J. Geog. Inf. Decis. Anal.* 7 (2), 47–71.
- Chan, F.T., Kumar, N., 2007. Global supplier development considering risk factors using fuzzy extended AHP-based approach. *Omega* 35 (4), 417–431.
- Charabi, Y., Gastli, A., 2011. PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. *Renew. Energ.* 36 (9), 2554–2561.
- Chen, Y.C., Wei, C., Yeh, H.C., 2008. Rainfall network design using kriging and entropy. *Hydrol. Process.* 22 (3), 340–346.
- Cheng, C., Thompson, R.G., 2016. Application of Boolean logic and GIS for determining suitable locations for temporary disaster waste management sites. *Int. J. Disast. Risk. Re.* 20, 78–92.
- Chezig, J., Pourghasemi, H.R., Naghibi, S.A., Moradi, H.R., Kheirkhah, Z.M., 2016. Assessment of a spatial multi-criteria evaluation to site selection underground dams in the Alborz Province. Iran. *Geocarto Int.* 31 (6), 628–646.
- Chung, J.H., Pak, J.M., Ahn, C.K., You, S.H., Lim, M.T., Song, M.K., 2017. Particle filtering approach to membership function adjustment in fuzzy logic systems. *Neurocomputing* 237, 166–174.
- Clinton, N., Holt, A., Scarborough, J., Yan, L.I., Gong, P., 2010. Accuracy assessment measures for object-based image segmentation goodness. *Photogramm. Eng. Remote Sens.* 76 (3), 289–299.
- Dong, Y., Zhang, G., Hong, W.C., Xu, Y., 2010. Consensus models for AHP group decision making under row geometric mean prioritization method. *Decis. Support Syst.* 49 (3), 281–289.
- Drobne, S., Lisec, A., 2009. Multi-attribute decision analysis in GIS: weighted linear combination and ordered weighted averaging. *Informatica.* 33 (4).
- Eastman, J.R., 2003. IDRISI Kilimanjaro: guide to GIS and image processing.
- Elaleem, M., 2012. Land suitability evaluation for sorghum based on boolean and fuzzy-multi-criteria decision analysis methods. *Int. J. Environ. Sci. Dev.* 3 (4), 357.
- El-Shirbeny, M.A., Abutaleb, K.A., 2018. Monitoring of water-level fluctuation of lake Nasser using altimetry satellite data. *Earth Syst. Environ.* 2, 367. <https://doi.org/10.1007/s41748-018-0053-y>.
- Emamgholi, M., Khosravi, K., Sedaii, N., 2015. Suitable site selections for gabion check dams construction using analytical hierarchy process and decision making methods. *J. Soil Environ.* 1, 35–44.
- Fitzgerald, N., Arántegui, R.L., McKeogh, E., Leahy, P., 2012. A GIS-based model to calculate the potential for transforming conventional hydropower schemes and non-hydro reservoirs to pumped hydropower schemes. *Energy* 41 (1), 483–490.
- Forzieri, G., Gardenti, M., Caparrini, F., Castelli, F., 2008. A methodology for the pre-selection of suitable sites for surface and underground small dams in arid areas: a case study in the region of Kidal. Mali. *Phys. Chem. Earth Pt. C.* 33 (1–2), 74–85.
- Ghazal, N.K., Salman, S.R., 2015. Determining the optimum site of small dams using remote sensing techniques and GIS. *Int. J. Sci. Eng. Res.* 69–73.
- Hameed, H., 2013. Water harvesting in Erbil Governorate, Kurdistan region, Iraq: detection of suitable sites using geographic information system and remote sensing. Student thesis series INES.
- Islam, M.N., Biswas, R., Shanta, S.R., Islam, R., Jakariya, M., 2018. Morphological dynamics of the Jamuna River in Kazipur sub district. *Earth Syst. Environ.* <https://doi.org/10.1007/s41748-018-0078-2>.
- Jabbar, M.F.A., Sissakian, V.K., 2010. Morphometry and genesis of the main Transversal Gorges in North and Northeast Iraq. *Iraqi Bull. Geol. Min.* 6 (1), 95–120.
- Jamali, I.A., Mörtberg, U., Olofsson, B., Shafique, M., 2014. A spatial multi-criteria analysis approach for locating suitable sites for construction of subsurface dams in Northern Pakistan. *Water Resour. Manag.* 28 (14), 5157–5174.
- Keshavarzi, A., Sarmadian, F., Heidari, A., Omid, M., 2010. Land suitability evaluation using fuzzy continuous classification (a case study: Ziaran region). *Mod. Appl. Sci.* 4 (7), 72.
- Larentis, D.G., Collischonn, W., Olivera, F., Tucci, C.E., 2010. Gis-based procedures for

- hydropower potential spotting. *Energy* 35 (10), 4237–4243.
- Lemos, J.A.S.V.D., 1988. A distinct element model for dynamic analysis of jointed rock with application to dam foundation and fault motion. Univ. of Minnesota, Ph. D. thesis-Minneapolis, 1987.
- Lewis, S.M., Fitts, G., Kelly, M., Dale, L., 2014. A fuzzy logic-based spatial suitability model for drought-tolerant switchgrass in the United States. *Comput. Electron. Agr.* 103, 39–47.
- Li, H.X., Wang, Y., Chen, C.P., 2017. Dempster-Shafer structure based fuzzy logic system for stochastic modeling. *Appl. Soft Comput.* 56, 134–142.
- Liu, Y., Sakamoto, S., Matsuo, K., Ikeda, M., Barolli, L., Xhafa, F., 2016. A comparison study for two fuzzy-based systems: improving reliability and security of JXTA-overlay P2P platform. *Soft Comput.* 20 (7), 2677–2687.
- Malczewski, J., 1999. GIS and Multicriteria Decision Analysis. John Wiley & Sons.
- Malczewski, J., 2004. GIS-based land-use suitability analysis: a critical overview. *Prog. Plann.* 62 (1), 3–65.
- Markowski, B., Lawler, S., 1977. Use of early fetal tissues obtained from suction termination of pregnancy. *Lancet* 1 (8004), 186–188.
- Marks, L.A., Dunn, E.G., Keller, J.M., Godsey, L.D., 1995, September. Multiple criteria decision making (MCDM) using fuzzy logic: an innovative approach to sustainable agriculture. In: *Uncertainty Modeling and Analysis, 1995, and Annual Conference of the North American Fuzzy Information Processing Society. Proceedings of ISUMA-NAFIPS'95, Third International Symposium on (503–508)*. IEEE.
- Minatour, Y., Khazaie, J., Ataei, M., Javadi, A.A., 2015. An integrated decision support system for dam site selection. *Sci. Iranica. Trans.A, Civ. Eng.* 22 (2), 319.
- Molina-Solana, M., Birch, D., Guo, Y.K., 2017. Improving data exploration in graphs with fuzzy logic and large-scale visualisation. *Appl. Soft Comput.* 53, 227–235.
- Noori, A.M., Hasan, S.F., Ajaj, Q.M., Mezaal, M.R., Shafri, M.A.S., 2018. Fusion of airborne hyperspectral and Worldview2 multispectral images for detailed urban land cover classification: a case study of Kuala Lumpur, Malaysia. *Int. J. Eng. Technol.* 7 (4.37), 202–206.
- Qiu, F., Chastain, B., Zhou, Y., Zhang, C., Sridharan, H., 2014. Modeling land suitability/capability using fuzzy evaluation. *Geo J.* 79 (2), 167–182.
- Qureshi, M.A., 2015. Dam/Reservoir Sites Selection Using Remote Sensing & Gis Techniques. Institute of Tibetan Plateau Research-CAS.
- Rajeev, V.S., Mahesha, A., 2008. Tropical river basin development-a case study in selection of sites for vented dams. *ISH J. Hydraulic Eng.* 14 (3), 18–27.
- Robinson, Jim, 2006. DCR Dam Safety Technical Advisory Table 1 Briefing, Department of Conservation and Recreation. Coserving Virginia's Natural and Recreational Resources, USA.
- Rojanamon, P., Chaisomphob, T., Bureekul, T., 2009. Application of geographical information system to site selection of small run-of-river hydropower project by considering engineering/economic/environmental criteria and social impact. *Renew. Sustain. Energy Rev.* 13 (9), 2336–2348.
- Romano, G., Dal Sasso, P., Liuzzi, G.T., Gentile, F., 2015. Multi-criteria decision analysis for land suitability mapping in a rural area of Southern Italy. *Land Use Policy.* 48, 131–143.
- Saaty, T., 1980. The analytic process: planning, priority setting, resources allocation. McGraw, New York.
- Safavian, A., Amani, M., 2015. Analysis of land suitability for small earth dams Using Multi Criteria Evaluation (MCE) in the Geographic Information System (GIS). *Int. Lett. Nat. Sci.* 42.
- Sauquet, E., 2006. Mapping mean annual river discharges: geostatistical developments for incorporating river network dependencies. *J. Hydrol.* 331 (1–2), 300–314.
- Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N.W., Clark, D.B., Dankers, R., Eisner, S., Fekete, B.M., Colón-González, F.J., Gosling, S.N., 2014. Multimodel assessment of water scarcity under climate change. *Proc. Natl. Acad. Sci.* 111 (9), 3245–3250.
- Sharbazeri, K., Ghafor, I., Muhammed, Q., 2009. Biostratigraphy of the cretaceous/tertiary boundary in the Sirwan Valley (Sulaimani Region, Kurdistan, NE Iraq). *Geol. Carpath.* 60 (5), 381–396.
- Sicat, R.S., Carranza, E.J.M., Nidumolu, U.B., 2005. Fuzzy modeling of farmers' knowledge for land suitability classification. *Agr. Syst.* 83 (1), 49–75.
- Sissakian, V.K., 2013. Geomorphology and morphometry of the Greater Zab River Basin, north of Iraq. *Iraqi Bull. Geol. Min.* 9 (3), 21–49.
- Skalak, K.J., Benthem, A.J., Schenk, E.R., Hupp, C.R., Galloway, J.M., Nustad, R.A., Wiche, G.J., 2013. Large dams and alluvial rivers in the Anthropocene: The impacts of the Garrison and Oahe Dams on the Upper Missouri River. *Anthropocene.* 2, 51–64.
- Stoms, D.M., McDonald, J.M., Davis, F.W., 2002. Fuzzy assessment of land suitability for scientific research reserves. *Environ. Manag.* 29 (4), 545–558.
- Thanoon, H.A., Ahmed, K.A., 2013. Hydrological information extraction for dams site selection using remote sensing techniques and geographical information system. *AL Rafdain Eng. J.* 21 (5), 102–114.
- Tsiko, R.G., Haile, T.S., 2011. Integrating geographical information systems, fuzzy logic and analytical hierarchy process in modelling optimum sites for locating water reservoirs: a case study of the Debub District in Eritrea. *Water.* 3 (1), 254–290.
- Van Ranst, E., Tang, H., Groenemam, R., Sinthurath, S., 1996. Application of fuzzy logic to land suitability for rubber production in peninsular Thailand. *Geoderma* 70 (1), 1–19.
- Yasser, M., Jahangir, K., Mohammad, A., 2013. Earth dam site selection using the analytic hierarchy process (AHP): a case study in the west of Iran. *Arab. J. Geosci.* 6 (9), 3417–3426.
- Zadeh, L.A., 1965. Fuzzy sets. *Inf. Control* 8 (3), 338–353.